

Please type a plus sign (+) inside this box → ☐

PTO/SB/05 (4/98)
Approved for use through 09/30/2000. OMB 0651-0032
Patent and Trademark Office U.S. DEPARTMENT OF COMMERCE

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 C.F.R. § 1.53(b))

Attorney Docket No. **FREIP025US**
First Inventor or Application Identifier **Seitz, et al.**
Title **Method and Device for Forming an Image**
Express Mail Label No. **EL362857905US**

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents

ADDRESS TO: Assistant Commissioner for Patents
Box Patent Application
Washington, DC 20231

1. ☒ Fee Transmittal Form (e.g., PTO/SB/17)
(Submit an original and a duplicate for fee processing)
2. ☒ Specification [Total Pages **16**]
(preferred arrangement set forth below)
 - Descriptive title of the invention
 - Cross References to Related Applications
 - Statement Regarding Fed sponsored R & D
 - Reference to Microfiche Appendix
 - Background of the Invention
 - Brief Summary of the Invention
 - Brief Description of the Drawings (if filed)
 - Detailed Description
 - Claim(s)
 - Abstract of the Disclosure
3. ☒ Drawing(s) (35 U.S.C. 113) [Total Sheets **3**]
4. Oath or Declaration [Total Pages **3**]
 - a. ☒ Newly executed (original or copy)
 - b. ☐ Copy from a prior application (37 C.F.R. § 1.63(d))
(for continuation/divisional with Box 16 completed)
 - i. ☐ DELETION OF INVENTOR(S)
Signed statement attached deleting
inventor(s) named in the prior application,
see 37 C.F.R. §§ 1.63(d)(2) and 1.33(b).

5. ☐ Microfiche Computer Program (Appendix)
6. Nucleotide and/or Amino Acid Sequence Submission
(if applicable, all necessary)
 - a. ☐ Computer Readable Copy
 - b. ☐ Paper Copy (identical to computer copy)
 - c. ☐ Statement verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

7. ☒ Assignment Papers (cover sheet & document(s))
8. ☐ 37 C.F.R. § 3.73(b) Statement (when there is an assignee) ☒ Power of Attorney
9. ☐ English Translation Document (if applicable)
10. ☐ Information Disclosure Statement (IDS)/PTO-1449 ☐ Copies of IDS Citations
11. ☒ Preliminary Amendment
12. ☒ Return Receipt Postcard (MPEP 503)
(Should be specifically itemized)
13. ☐ Small Entity Statement(s) ☐ Statement filed in prior application, Status still proper and desired (PTO/SB/09-12)
14. ☐ Certified Copy of Priority Document(s) (if foreign priority is claimed)
15. ☐ Other: _____

* NOTE FOR ITEMS 1 & 13: IN ORDER TO BE ENTITLED TO PAY SMALL ENTITY FEES, A SMALL ENTITY STATEMENT IS REQUIRED (37 C.F.R. § 1.27), EXCEPT IF ONE FILED IN A PRIOR APPLICATION IS RELIED UPON (37 C.F.R. § 1.28).

16. If a CONTINUING APPLICATION, check appropriate box, and supply the requisite information below and in a preliminary amendment:

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No. _____ / _____
Prior application information Examiner _____ Group / Art Unit: _____

For CONTINUATION or DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 4b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

17. CORRESPONDENCE ADDRESS

☒ Customer Number or Bar Code Label



or ☐ Correspondence address below

021121

Name	PATENT TRADEMARK OFFICE			
Address				
City	State	Zip Code		
Country	Telephone	Fax		

Name (Print/Type)	Carl Oppedahl	Registration No. (Attorney/Agent)	32,746
Signature	<i>Carl Oppedahl</i>	Date	

Burden Hour Statement: This form is estimated to take 0.2 hours to complete. Time will vary depending upon the needs of the individual case. Any comments on the amount of time you are required to complete this form should be sent to the Chief Information Officer, Patent and Trademark Office, Washington, DC 20231. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Assistant Commissioner for Patents, Box Patent Application, Washington, DC 20231

11/12/99
jc674 U.S. PTO

FREIP025US

A

TRANSMITTAL FORM

U.S. Application No. : To be assigned
Application of: : Seitz, et al.
Filing Date : November 12, 1999
Title: : Method and Device for Forming an Image
Attorney Docket No. : FREIP025US

Enclosures:

- Utility Patent application Transmittal (PTO/SB/05)
- Fee Transmittal (PTO/SB/17)
- Preliminary Amendment - 3 Pages
- Check No. 005580 for \$830.00
- Specification - 16 Pages
- Drawings - 3 Pages
- Combined Declaration and Power of Attorney - 3 Pages
- Recordation Form Cover Sheet
- Assignment - 2 Pages

Date: November 12, 1999

Carl Oppedahl

Carl Oppedahl, Reg. No. 32,746
Marina T. Larson, Reg. No. 32,038
OPPEDAHL & LARSON LLP
P.O. Box 5270
Frisco, CO 80443-5270
Tel: 970-668-2050
Fax: 970-668-2082

CERTIFICATE OF EXPRESS MAIL UNDER 37 C.F.R. § 1.10

"Express Mail" Mailing Label

EL362857905US

Date of Deposit November 12, 1999. I hereby certify that this paper or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" Service under 37 C.F.R. § 1.10 on the date indicated above and is addressed to:

Box Patent application
Assistant Commissioner for Patents
Washington, D.C. 20231

Susan Howard
(Type or print Name of person mailing paper or fee)

Susan Howard
(Signature of person mailing paper or fee)

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: CSEM Centre Suisse D'Electronique et de Microtechnique SA
Serial No.: To be assigned
Filed: herewith
For: Method and Device for Forming an Image

PRELIMINARY AMENDMENT

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Preliminary to the examination of the above-reference application, please make the following amendments:

In the claims:

Claim 3, line 1, delete "claim 1 or 2" and insert --claim 1--.

Claim 4, line 1, delete "one of the claims 1-3" and insert --claim 1--.

Claim 5, line 1, delete "one of the claims 1-4" and insert --claim 1--.

Claim 6, line 1, delete "one of the claims 1-5" and insert --claim 1--.

Claim 7, line 1, delete "one of the claims 1-6" and insert --claim 1--.

Claim 10, line 1, delete "one of the claims 1-9" and insert --claim 1--.

Please amend claim 11 as follows:

11. (amended) [Method according to claim 10 and one of the claims 8 or 9], Method according to claim 1, where in step b), said output values (P_1, \dots, P_n) are combined into a combined output value (P_{out}) by means of a merging function ($f(x_1, \dots, x_n)$) which is truly monotonic, continuous and continuously differentiable in all said output values (P_1, \dots, P_n), wherein $n = 2$ for all subsets (11, 11', ...) of pixels, wherein step a), a longer exposure (22, 22', ...) and a shorter exposure (26, 26', ...) are performed wherein said merging function ($f(x_1, x_2)$) has the following properties:

- (i) preference is given to the output value (x_1) obtained from the longer exposure (22, 22', ...) when said output values (x_1, x_2) or a combination of said output values ($(x_1 + x_2)/2$) lie beneath a given lower limit (x_{low});
- (ii) preference is given to the output value (x_2) obtained from the shorter exposure (26, 26', ...) when said output values (x_1, x_2) or a combination of said output values ($(x_1 + x_2)/2$) lie above a given upper limit (x_{up});
- (iii) said merging function ($f(x_1, x_2)$) increases truly monotonically in said output values (x_1, x_2) when said output values (x_1, x_2) lie between said lower limit (x_{low}) and said upper limit (x_{up}).

Claim 13, line 1, delete "one of the claims 1-12" and insert --claim 1--.

Claim 14, line 1, delete "one of the claims 1-13" and insert --claim 1--.

REMARKS

This amendment is filed to make corrections to the application to place it in better form for prosecution in the United States Patent Office and to eliminate multiple dependent claims.

No new matter has been added.

Respectfully submitted,



Carl Oppedahl
Oppedahl & Larson LLP
P O Box 5270
Frisco, CO 80443-5270
970-668-2050
oppedahl@patents.com

METHOD AND DEVICE FOR FORMING AN IMAGE

The invention relates to a method for forming an image and to an image sensor with an active area containing a plurality of pixels. It makes possible a wide dynamic range but obviates the need for a storage of complete images. It reduces temporal aliasing to a minimum and eliminates spatial aliasing.

- 5 Image sensing devices can be realized with semiconductors based on their capability to convert locally impinging light energy into a proportional amount of electronic charge. More specifically, if a picture element is exposed during time T to the local light power P_L , a charge signal Q is created according to the equation

$$Q = P_L \gamma T \quad (1)$$

- 10 where γ denotes the conversion efficiency of photons into electronic charge, which strongly depends on the wavelength spectrum of the incoming light. This charge Q , often called photocharge, can be stored in a two-dimensional array of charge storage devices such as a reverse biased diode (as in photodiode-based image sensors) or such as a pre-charged metal-oxide-semiconductor capacitance (as in charge-coupled
15 devices, CCDs).

Due to the limited storage capacity of these storage devices, the ratio of maximum storable photocharge to photocharge detection noise, called dynamic range, is also limited. In typical CCD or photodiode image sensors, the available dynamic range is

of the order of 1'000:1. Unfortunately, natural scenes (where there is no control of lighting conditions) and indoor scenes with highly varying illumination have a dynamic range of between 100'000:1 and 1'000'000:1.

00435945 11299
5 The dynamic range of an image sensor can be increased by making use of the exposure time dependence shown in Equation (1). The patents US-5,144,442, US-5,168,532, US-5,309,243 and US-5,517,242 describe methods based on the acquisition of two or more images, each with its individual exposure time. At least one complete image has to be stored with these methods, preferentially in digital form by making use of a frame-store. This results in a complex and cost-intensive system. Moreover, the two or more images with different exposure times cannot be taken concurrently, therefore not representing the same moving scenes at different exposure levels but rather at different points in time. Consequently, such methods exhibit undesirable temporal aliasing.

15 This problem can be overcome by a method described in US-5,483,365 and US-5,789,737. The approach taken in US-5,483,365 consists of using alternate image sensor rows for different exposure times. US-5,789,737 teaches the use of several picture elements (pixels), each with its own sensitivity. In both cases, the brightness information may be acquired concurrently in time but not at the identical geometrical pixel location. This implies spatial undersampling and aliasing, which is particularly undesirable in the case of so-called highlights, i.e., localized very bright pixel values usually caused by specular reflections at objects in the scene.

25 Once a plurality of images have been taken at different exposure times, they have to be fused or merged to form one single piece of pixel information of wide dynamic range. Patents US-4,647,975, US-5,168,532 and US-5,671,013 teach that the information is copied from the most suitable of the images, according to some

selection rule. This value is then multiplied with a suitable factor that corrects for the respective exposure time. This method works well only for ideal image sensors with completely linear pixel behavior, irrespective of illumination level and exposure time. In practical image sensors, this is not true, and the resulting response curve
5 (output value vs. illumination levels) shows discontinuities. This is particularly disturbing if the resulting images are processed further, leading to false contours and erroneous contrast values. An improvement is taught by US-5,517,242 claiming an algorithm where the output value at each pixel site is calculated in a certain brightness range as a linear combination of the values at two different exposure
10 times, corrected by an appropriate factor that compensates for the different exposure times. In all these methods, either complete images have to be stored, or complex and surface-intensive electronic circuitry in each pixel is required.

It is the aim of the invention to overcome the aforementioned disadvantages of the prior-art methods and image sensors. In particular, the invention shall make possible
15 a wide dynamic range but obviate the need for a storage of complete images. It shall, moreover, reduce temporal and spatial aliasing to a minimum. The problem is solved by the invention as defined in the independent claims.

The invention is based on the local acquisition of pixel information for different exposure times, following Equation (1). The problems of the requirement for
20 complete image storage and of temporal or spatial sampling at different points in time or in space are overcome by using a type of image sensors in which a subset of pixels (e.g., a single pixel or a row of pixels) can be individually reset and read out. A preferred embodiment is an active pixel sensor (APS) pixel that can be fabricated in standard CMOS technology. Such an APS is described for example in E.R.
25 Fossum, "Active Pixel Sensors: Are CCD's Dinosaurs?", *Proc. SPIE* 1900 (1993) 2-14.

The method according to the invention for forming an image uses an image sensor with an active area containing a plurality of pixels. The method comprises

- a) in n interrogation runs performed on a first subset of pixels, where n is an integer and $n \geq 2$, resetting the first subset of pixels, exposing the first subset of pixels
5 and reading out the output value(s) of the first subset of pixels;
- b) combining said output values into a first combined output value;
- c) repeating steps a) and b) for at least one second subset of pixels.

In order to obtain a complete image information, steps a) and b) are preferably repeated until each pixel has been read out at least once.

- 10 The subset is understood to contain less pixels than the whole image sensor. The subset may be, e.g., a row, a column or a single pixel of the image sensor. All subsets preferably have the same number of pixels. The subsets are preferably defined before performing step a) of the method by partitioning the active area of the image sensor. The processing of one subset of pixels may temporally overlap with the processing of
15 the following subset of pixels.

- In a preferred embodiment of the invention, $n = 2$ for all subsets of pixels, i.e., each subset is exposed twice, with a longer and a shorter exposure time. A first reset command is issued to one pixel or all pixels in one row. After a first, long exposure time T_{long} , the output value(s) P_{long} of the pixel or all pixels in this row is/are read out
20 and immediately stored in analog or digital form. Immediately afterwards, the pixel or row of pixels is reset and exposed during a second, short exposure time T_{short} . The output value(s) P_{short} of the pixel or row of pixels is/are read out. This information is either again stored in analog or digital fashion, or it can immediately be processed together with the previously stored pixel or row-of-pixel output values, according to
25 the procedure given below. Depending on the desired value of T_{long} , the pixel or row

of pixels can immediately be reset for a maximum value of exposure time, or it/they can be reset at a later time. After this pixel or row of pixels has been reset and read twice, the next pixel or row of pixels is interrogated in the same fashion.

In the method according to the invention, the timing used to reset and interrogate the sequence of pixels in an image sensor is important. The ratio $t = T_{\text{long}}/T_{\text{short}}$ is chosen to increase significantly the dynamic range of the image sensor, insuring, however, an overlap between the images. For example, the dynamic range of an image sensor can be increased by the method according to the invention from 70 dB to 110 dB using a ratio of $t = 100$. During the long integration time, many pixels or rows of pixels can be interrogated and reset a first time, exposed during a second (much shorter) time interval, interrogated and reset a second time. Preferably, these operations are performed on all other pixels or rows of pixels during the long integration time of one pixel or row of pixels, so that the ratio $t = T_{\text{long}}/T_{\text{short}}$ is equal to the total number of pixels or rows of pixels of the image sensor. Compared with the state of the art, this has three advantages. Firstly, at most two rows of pixel data have to be stored at one time, and it is completely unnecessary to acquire and store complete images before processing and merging the data. Secondly, the short exposure time occurs immediately after the long one, effectively assuring a quasi-instantaneous exposure. Thirdly, the same pixel location is employed to acquire image data for the different exposure times and no spatial aliasing can occur.

During the first, long exposure, dark objects are detected, whereas very bright objects are not, due to saturation of the corresponding pixels; during the second, short exposure, bright objects are detected, whereas very dark objects are not, due to a too weak signal. According to the invention, the output signals of both exposures are suitably combined in order to increase the dynamic range of the image sensor. Due to imperfections in the practical realizations of the above-described method and device, the two pixel output values P_{short} and P_{long} measured for the two exposure times will

- 6 -

not be related ideally through the ratio $t = T_{\text{long}}/T_{\text{short}}$, i.e., P_{long} will be close to but not identical with $t \cdot P_{\text{short}}$. For this reason we need an algorithm that combines the two values in a manner that does not lead to artifacts in subsequent image processing and interpretation procedures. For this, it is important to find a method that ensures a
 5 monotonic, smooth transition from values taken with long to values taken with short exposure times.

The invention encompasses the following method to arrive at this goal. For each pixel or row of pixels, the two pixel output values P_{long} and P_{short} are processed into a single value P_{out} , using a merging function $f(x_1, x_2)$:

10 $P_{\text{out}} = f(P_{\text{long}}, t \cdot P_{\text{short}})$.

The merging function $f(x_1, x_2)$ is preferably truly monotonic, continuous and continuously differentiable in both independent variables x_1 and x_2 . It should have the following properties:

- (i) $f(x_1, x_2) = x_1$ for $x_1 \leq x_{\text{low}}$
 15 (ii) $f(x_1, x_2) = x_2$ for $x_1 \geq x_{\text{up}}$, where $0 \leq x_{\text{low}} < x_{\text{up}}$
 (iii) $f(x_1, x_2)$ increases truly monotonically
 in x_1 and x_2 for $x_{\text{low}} < x_1 < x_{\text{up}}$

In other words, the merging function $f(x_1, x_2)$ preferably obeys the following rules:

- (i) Preference is given to the output value x_1 obtained from the longer exposure
 20 when the output values x_1 , x_2 or an appropriate combination of the output values x_1 , x_2 , e.g., their average $(x_1 + x_2)/2$, lie beneath a given lower limit x_{low} ;
 (ii) Preference is given to the output value x_2 obtained from the shorter exposure
 25 when the output values x_1 , x_2 or an appropriate combination of the output values x_1 , x_2 , e.g., their average $(x_1 + x_2)/2$, lie above a given upper limit x_{up} ;

- (iii) The merging function $f(x_1, x_2)$ increases truly monotonically in the output values x_1, x_2 when the output values x_1, x_2 lie between the lower limit x_{low} and the upper limit x_{up} .

The parameters x_{up}, x_{low} are chosen according to the following criteria.

- 5 • The lower limit x_{low} is given by the minimum illumination required for the short exposure time. For lower illumination, the sensor output corresponds essentially to noise and cannot be interpreted.
- The upper limit x_{up} corresponds to the output value computed for maximum allowable light intensity for the long exposure time. At higher illumination, the
- 10 sensor shows first a non-linear response and will eventually saturate.

The parameters x_{up}, x_{low} have either preset values, or can vary with time, e.g., be determined from earlier output signals and thus adapt to the actual illumination of the image sensor.

- 15 A preferred example of a merging function $f(x_1, x_2)$ for the range for $x_{low} < x_1 < x_{up}$ is the following:

$$f(x_1, x_2) = \sqrt{cx_1^2 + (1-c)x_2^2} \quad \text{with} \quad c = (x_1 - x_{up}) / (x_{low} - x_{up}) .$$

- 20 This merging function notably exhibits the following desirable properties. It gives increased preference to the value x_1 when x_1 is close to x_{low} , and it gives increased preference to the value x_2 when x_1 is close to x_{up} . It is truly monotonic, continuous and continuously differentiable in x_1 and x_2 , inhibiting banding and discontinuous jumps in subsequent algorithms that calculate and employ the first spatial derivative of the local brightness values. Moreover, it is symmetric in x_1 and x_2 .

The above considerations for an example with two interrogation runs, i.e., $n = 2$, may be generalized for the case where $n \geq 2$. Then a merging function $f(x_1, \dots, x_n)$ is used for combining n output values P_1, \dots, P_n into a single value P_{out} according to the formula

5
$$P_{\text{out}} = f(P_1, t_2 \cdot P_2, \dots, t_n \cdot P_n) ,$$

where t_2, \dots, t_n are appropriate scaling factors.

The merging function can be evaluated either in a general-purpose digital computation unit, a dedicated digital or analog computation unit that is preferentially placed on the same chip as the sensor, or the merging function can be realized with a
10 lookup-table, either partially or completely.

The image sensor according to the invention comprises an active area containing a plurality of pixels, whereby at least two subsets of pixels may be individually interrogated, i.e., they can individually be reset and read out. The image sensor further comprises means for individually interrogating subsets of pixels, means for
15 combining output values of said subsets into combined output values, and means for electrically outputting said combined output values.

In the following, the invention and a preferred embodiment thereof are described in more detail with reference to the drawings, wherein:

Fig. 1 shows the output of one pixel in the method according to the invention;

20 Fig. 2 shows the architecture of an image sensor suited for the method according to the invention;

Fig. 3 shows a flow chart of the method according to the invention; and

Fig. 4 shows an output characteristic of a multiple-exposure image sensor according to the invention.

5 **Figure 1** schematically shows the output P of one given pixel as a function of time T in the method according to the invention. The figure illustrates an example in which two exposures, a first exposure 31 with a long exposure time T_{long} and a second exposure 34 with a short exposure time T_{short} , are performed on each subset of pixels. After the first exposure 31, the pixel output value is read out 32 and reset 33 for a first time. A second read-out 35 and, optionally, a second reset 36 are performed
10 after the second exposure 34. Then, the pixel is ready for a further interrogation cycle. Of course, other variants of the method are possible in which, e.g., the first exposure time is shorter and the second one is longer, or in which more than two exposures are performed in one interrogation cycle.

Figure 2 shows a schematic of the architecture of an image sensor suited for carrying
15 out the method according to the invention. In this exemplified embodiment, the image sensor has an active area 1 consisting of a matrix of 256×256 pixels 10, 10', ... arranged in rows 11, 11', ... and columns 12, 12', ... A row address decoder 2 and a reset address decoder 3 are provided for the rows 11, 11', ... The reset address decoder has the function of an electronic row shutter. A column driver 4 and a
20 column address decoder 5 are provided for the columns 12, 12', ... The image signals are outputted via a video output 6.

Referring to the image sensor of Fig. 2, **Figure 3** shows a flow chart of a preferred embodiment of the method according to the state of the art. A read-out sequence for one full frame with two exposures (cf. Fig. 1) is shown. In this embodiment, the

subsets of pixels are the 256 rows 11, 11', ... of the image sensor, each subset thus consisting of 256 pixels 10, 10', ... The first subset to be interrogated is, e.g., row No. 255. A first reset command 21 is issued to all pixels in row No. 255. After a first, long exposure time 22, the output values $P_{long}^{(255,255)}$ to $P_{long}^{(255,0)}$ of all 256 pixels in this

5 row No. 255 are read out 23 and immediately stored 24 in analog or digital form. Immediately afterwards, row No. 255 is reset 25 and exposed during a second, short exposure time 26. The output values $P_{short}^{(255,255)}$ to $P_{short}^{(255,0)}$ of all 256 pixels are read out

27. This information is either again stored in analog or digital fashion, or it can immediately be processed 28 together with the previously stored output values

10 $P_{long}^{(255,255)}$ to $P_{long}^{(255,0)}$. After row No. 255 has been reset and read twice, the next row No. 254 is interrogated in the same fashion; the corresponding elements in Fig. 3 are designated with the same reference numbers as for row No. 255 and additional apostrophes, e.g., reference number 21' stands for a first reset command to all pixels in row. No. 254. These steps are performed for each row, ending with row No. 0.

15 Then each pixel has been read out once, in two interrogation runs, and a first complete image can be built up 29 from the processed output values $P_{out}^{(255)}$ to $P_{out}^{(0)}$. This procedure can be repeated as many times as desired.

Figure 4 schematically shows an output characteristic of a multiple-exposure image sensor according to the invention, i.e., output values P as functions of the light

20 intensity I . Again, an exemplified embodiment with two exposures is discussed. A first graph 41 in Fig. 4 represents the output P_{long} for the long exposure. For low intensities, P_{long} increases linearly with the intensity I ; above an upper limit x_{up} , it flattens due to saturation. A second graph 42 in Fig. 4 represents output P_{short} for the short exposure, multiplied with a scaling factor t , i.e., $t \cdot P_{short}$. Beneath a lower limit

25 x_{low} , the signal is too weak and therefore useless; for higher intensities, $t \cdot P_{short}$ increases linearly with the intensity I . A third graph 43 in Fig. 4 shows an example for a combined output

- 11 -

$$P_{\text{out}} = f(P_{\text{long}}, t \cdot P_{\text{short}}) .$$

The merging function $f(x_1, x_2)$ has the following properties:

- (i) $f(x_1, x_2) = x_1$ for $x_1 \leq x_{\text{low}}$
- (ii) $f(x_1, x_2) = x_2$ for $x_1 \geq x_{\text{up}}$, where $0 \leq x_{\text{low}} < x_{\text{up}}$
- 5 (iii) $f(x_1, x_2)$ increases truly monotonically
in x_1 and x_2 for $x_{\text{low}} < x_1 < x_{\text{up}}$

10 This merging function gives increased preference to the value x_1 when x_1 is close to x_{low} , and it gives increased preference to the value x_2 when x_1 is close to x_{up} . Thus the combined output P_{out} exhibits a smooth transition from the long-exposure range to the scaled short-exposure range.

This invention is not limited to the preferred embodiments described above, to which variations and improvements may be made, without departing from the scope of protection of the present patent.

CLAIMS

1. Method for forming an image by means of an image sensor with an active area (1) containing a plurality of pixels (10, 10', ...), comprising
 - a) in n interrogation runs performed on a first subset (11) of pixels, where n is an integer and $n \geq 2$, resetting (21, 25) the first subset of pixels (11), exposing (22, 26) the first subset (11) of pixels and reading out (23, 27) the output value(s) ($\underline{P}_{long}^{(255)}$, $\underline{P}_{short}^{(255)}$) of the first subset (11) of pixels;
 - b) combining said output values ($\underline{P}_{long}^{(255)}$, $\underline{P}_{short}^{(255)}$) into a first combined output value ($\underline{P}_{out}^{(255)}$);
 - c) repeating steps a) and b) for at least one second subset (11') of pixels.
2. Method according to claim 1, wherein said subsets are rows (11, 11', ...), columns (12, 12', ...) or single pixels (10, 10', ...) of the image sensor.
3. Method according to claim 1 or 2 wherein prior to step a), the active area (1) of the image sensor is partitioned into subsets (11, 11', ...) with equal numbers (256) of pixels (10, 10', ...).
4. Method according to one of the claims 1-3, wherein in step a), at least one of said output value(s) ($\underline{P}_{long}^{(255)}$) is/are stored (24, 24', ...).
5. Method according to one of the claims 1-4, wherein steps a) and b) are repeated until each pixel (10, 10', ...) has been read out at least once.

6. Method according to one of the claims 1-5, wherein the processing of one subset (11) of pixels temporally overlaps with the processing of the following subset (11') of pixels.
7. Method according to one of the claims 1-6, wherein $n = 2$ for all subsets (11, 11', ...) of pixels.
8. Method according to claim 7, wherein in step a), a longer exposure (22, 22', ...) and a shorter exposure (26, 26', ...) are performed.
9. Method according to claim 8, wherein during said longer exposure (22) of one subset (11), steps b) are performed for all other subsets (11', ...).
10. Method according to one of the claims 1-9, wherein in step b), said output values (P_1, \dots, P_n) are combined into a combined output value (P_{out}) by means of a merging function ($f(x_1, \dots, x_n)$) which is truly monotonic, continuous and continuously differentiable in all said output values (P_1, \dots, P_n).
11. Method according to claim 10 and one of the claims 8 or 9, wherein said merging function ($f(x_1, x_2)$) has the following properties:
 - (i) Preference is given to the output value (x_1) obtained from the longer exposure (22, 22', ...) when said output values (x_1, x_2) or a combination of said output values ($(x_1 + x_2)/2$) lie beneath a given lower limit (x_{low});
 - (ii) Preference is given to the output value (x_2) obtained from the shorter exposure (26, 26', ...) when said output values (x_1, x_2) or a combination of said output values ($(x_1 + x_2)/2$) lie above a given upper limit (x_{up});

- (iii) Said merging function ($f(x_1, x_2)$) increases truly monotonically in said output values (x_1, x_2) when said output values (x_1, x_2) lie between said lower limit (x_{low}) and said upper limit (x_{up}).

12. Method according to claim 11, wherein said merging function ($f(x_1, x_2)$) is defined
5 by

$$f(x_1, x_2) = \sqrt{cx_1^2 + (1-c)x_2^2} \quad \text{with } c = (x_1 - x_{up}) / (x_{low} - x_{up})$$

for $x_{low} < x_1 < x_{up}$.

13. Method according to one of the claims 1-12, wherein said image sensor is an active pixel sensor (APS).
- 10 14. Method according to one of the claims 1-13, wherein said output values (P_{long} , P_{short}) are combined using a general-purpose digital computation unit, a dedicated digital or analog computation unit or a lookup table.
- 15 15. Image sensor for performing the method according to claim 1, comprising
an active area (1) containing a plurality of pixels (10, 10', ...), whereby at least
two subsets (11, 11', ...) of pixels allow an individual interrogation;
means (2, 3) for individually interrogating subsets (11, 11', ...) of pixels;
means for combining output values ($\underline{P}_{long}^{(255)}$, $\underline{P}_{short}^{(255)}$) of said subsets (11, 11', ...)
into combined output values ($\underline{P}_{out}^{(255)}$); and
means (6) for electrically outputting said combined output values ($\underline{P}_{out}^{(255)}$).

- 15 -

16. Image sensor according to claim 15, said image sensor being an active pixel sensor (APS).

- 16 -

ABSTRACT

The method for forming an image with a wide dynamic range makes use of an image sensor containing subsets of pixels that can be individually reset. After an initial reset (21), a pixel or row of pixels is exposed (22) for a first time interval and the gray value(s) ($P_{long}^{(255)}$) are read out (23) and stored (24). The pixel or row of pixels is then reset (25) and exposed (26) for a second, shorter time interval. The second gray value(s) ($P_{short}^{(255)}$) is/are read out (27) and either stored or immediately combined (28) with the first gray value(s) ($P_{long}^{(255)}$) by means of a merging function (f). The merging function (f) ensures a monotonic, smooth change in output from the lowest to the highest gray values. The procedure is repeated for all pixels or rows of pixels in the image sensor, thus obviating the need for the storage of complete images. The method reduces temporal aliasing to a minimum and eliminates spatial aliasing.

(Figure 3).

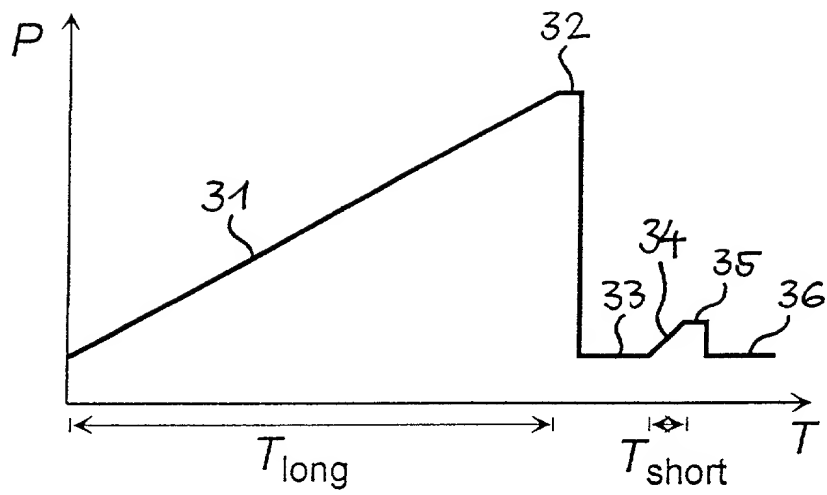


Fig. 1

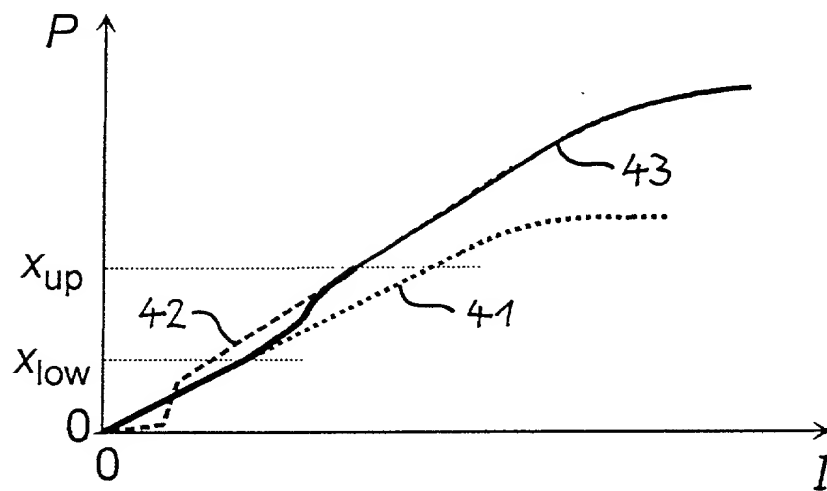


Fig. 4

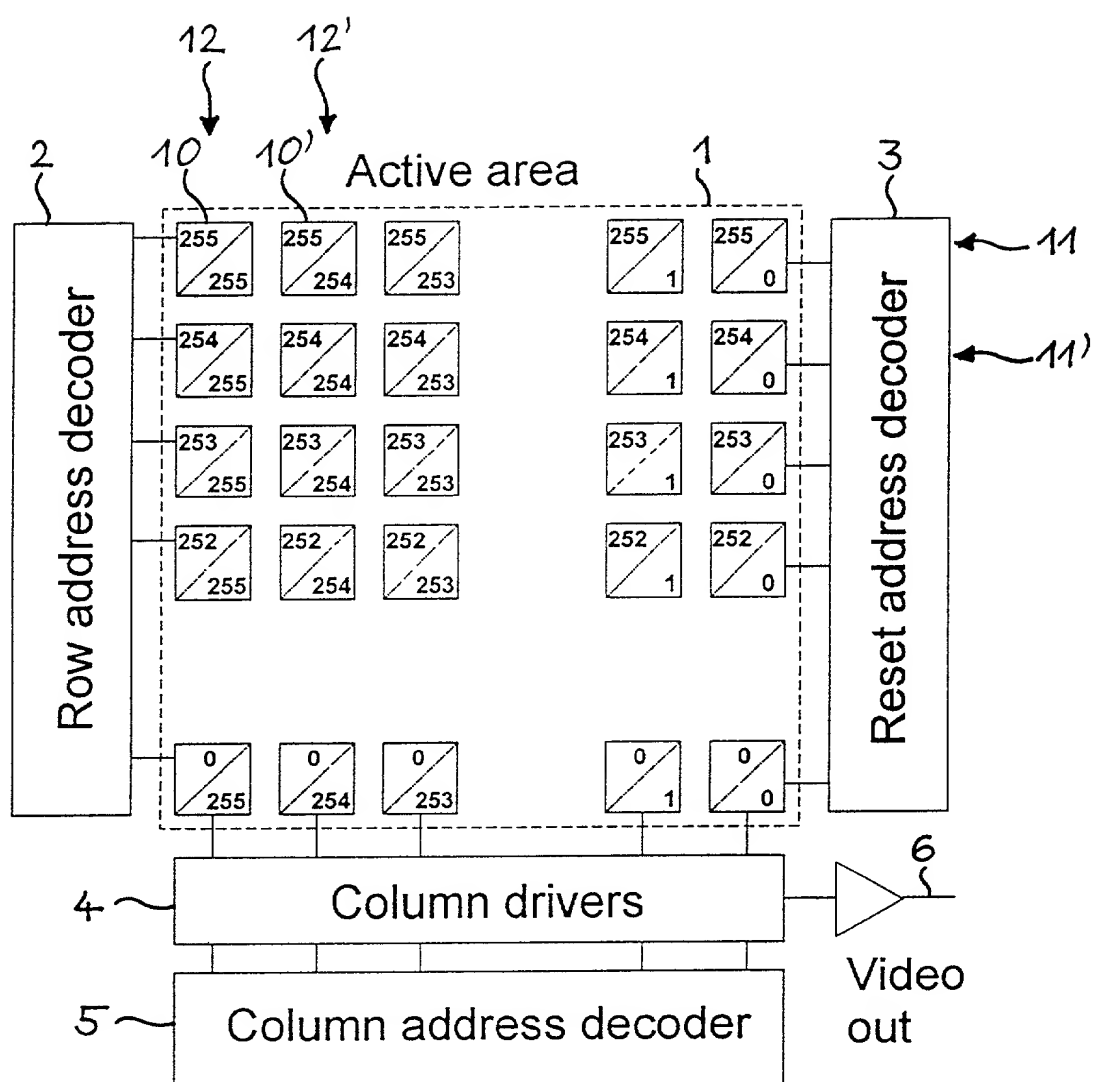


Fig. 2

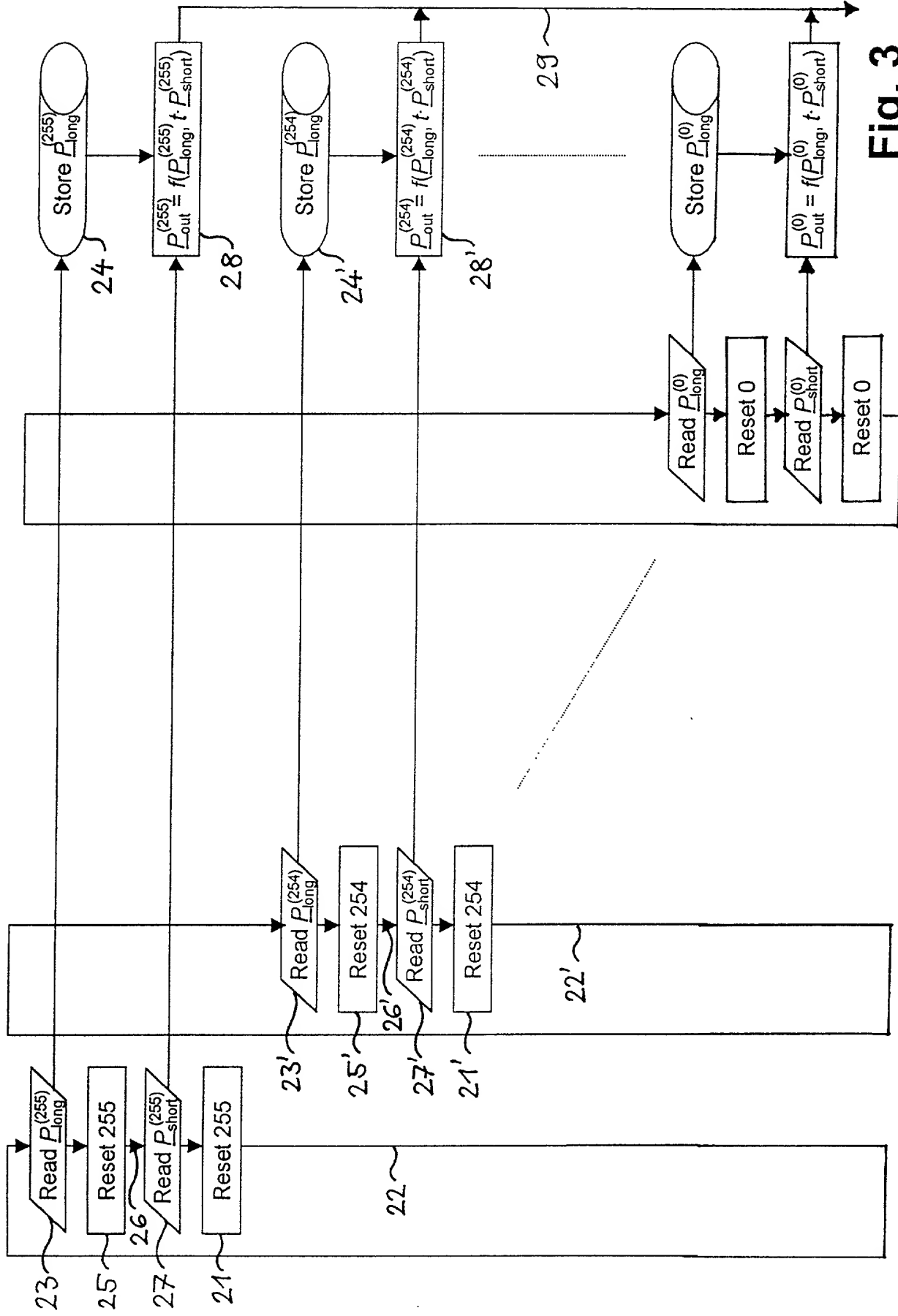


Fig. 3

OPPEDAHL & LARSON

FILE NO. FREI-P-02516

**COMBINED DECLARATION
AND POWER OF ATTORNEY**

As a below named inventor, I hereby declare that:

My citizenship, residence and post office address are as listed below next to my name.

I believe I am the original, first and ☐ sole/☒ joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled: METHOD AND DEVICE FOR FORMING AN IMAGE

the specification of which

(a) ☒ is attached hereto.

(b) ☐ was filed on _____ as Application Serial No. _____ and was amended on _____

(c) ☐ was described and claimed in International Application No. _____ filed on _____ and amended on _____

Acknowledgment of Duty of Disclosure

I hereby state that I have reviewed and understood the content of the above identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose information which is material to the patentability of the subject matter claimed in this application in accordance with Title 37, Code of Federal Regulations § 1.56(a).

Continuation-in-Part Application

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code § 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, § 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.) (Filing Date) (Status)(patented,pending,abandoned)

(Application Serial No.) (Filing Date) (Status)(patented,pending,abandoned)

Power of Attorney

I hereby appoint Carl Oppedahl, PTO Reg. No. 32,746, Marina T. Larson, PTO Reg. No. 32,038, and Nancy J. Parsons, PTO Reg. No. 40,384 of the firm of OPPEDAHL & LARSON LLP, having office at P.O. Box 5270, 611 Main Street, Frisco, CO 80443 as attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

SEND CORRESPONDENCE TO:
OPPEDAHL & LARSON LLP
P.O. Box 5270
Frisco, CO 80443-5270

DIRECT TELEPHONE CALLS TO:
OPPEDAHL & LARSON LLP
(970) 668-2080

OPPEDAHL & LARSON

FILE NO. FREI P-025US

Claim for Priority

I hereby claim priority under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate listed below and have identified any foreign applications for patent or inventor's certificate having a filing date before that of the application on which priority is claimed.

EARLIEST FOREIGN APPLICATION(S), FILED WITHIN TWELVE MONTHS (6 MONTHS FOR DESIGN) PRIOR TO SAID APPLICATION				
COUNTRY	APPLICATION NO.	DATE OF FILING (day/month/year)	DATE OF ISSUE (day/month/year)	PRIORITY CLAIMED
EP	98 121 897.7	11/18/1998		YES <input checked="" type="checkbox"/> NO <input type="checkbox"/>
				YES <input type="checkbox"/> NO <input type="checkbox"/>
				YES <input type="checkbox"/> NO <input type="checkbox"/>

FOREIGN APPLICATION(S), IF ANY, FILED MORE THAN 12 MONTHS (6 MONTHS FOR DESIGN) PRIOR TO SAID APPLICATION				
COUNTRY	APPLICATION NO.	DATE OF FILING (day/month/year)	DATE OF ISSUE (day/month/year)	

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements are made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

NAME OF SOLE OR FIRST INVENTOR	LAST NAME SEITZ	FIRST NAME PETER	MIDDLE NAME
RESIDENCE & CITIZENSHIP	CITY OF RESIDENCE URDORF	STATE OR COUNTRY OF RESIDENCE SWITZERLAND	COUNTRY OF CITIZENSHIP CH
POST OFFICE ADDRESS BERGSTRASSE 35		CITY URDORF	STATE/COUNTRY ZIP CODE 8902 SWITZERLAND
DATE X October 28, 1999		SIGNATURE X Seitz Peter	

- ☒ Signature for additional joint inventor attached. Number of Pages 1.
☐ Signature by Administrator(trix) or legal representative for deceased or incapacitated inventor. Number of Pages .
☐ Signature for inventor who refuses to sign or cannot be reached by person authorized under 37 CFR § 1.47. Number of Pages .

00430015-111209

OPPEDAHL & LARSON

FILE NO.FREI.P-025US

NAME OF SECOND INVENTOR	LAST NAME LANG	FIRST NAME GRAHAM	MIDDLE NAME K.
RESIDENCE & CITIZENSHIP	CITY OF RESIDENCE HAUSEN AM ALBIS	STATE OR COUNTRY OF RESIDENCE SWITZERLAND	COUNTRY OF CITIZENSHIP GB
POST OFFICE ADDRESS ROSRAINSTRASSE 75		CITY HAUSEN AM ALBIS	STATE/COUNTRY ZIP CODE 8915 SWITZERLAND
DATE X October 28 1999		SIGNATURE X Lang Graham Keith	
NAME OF THIRD INVENTOR	LAST NAME BLANC	FIRST NAME NICOLAS	MIDDLE NAME
RESIDENCE & CITIZENSHIP	CITY OF RESIDENCE OBERRIEDEN	STATE OR COUNTRY OF RESIDENCE SWITZERLAND	COUNTRY OF CITIZENSHIP CH
POST OFFICE ADDRESS BLEIERSTRASSE 23 a		CITY OBERRIEDEN	STATE/COUNTRY ZIP CODE 8942 SWITZERLAND
DATE X October 28 1999		SIGNATURE X Blanc Nicolas	
NAME OF FOURTH INVENTOR	LAST NAME	FIRST NAME	MIDDLE NAME
RESIDENCE & CITIZENSHIP	CITY OF RESIDENCE	STATE OR COUNTRY OF RESIDENCE	COUNTRY OF CITIZENSHIP
POST OFFICE ADDRESS		CITY	STATE/COUNTRY ZIP CODE
DATE		SIGNATURE	
NAME OF FIFTH INVENTOR	LAST NAME	FIRST NAME	MIDDLE NAME
RESIDENCE & CITIZENSHIP	CITY OF RESIDENCE	STATE OR COUNTRY OF RESIDENCE	COUNTRY OF CITIZENSHIP
POST OFFICE ADDRESS		CITY	STATE/COUNTRY ZIP CODE
DATE		SIGNATURE	

09430015-111200